# Part V
# Ensuring Long-Term Protection

## Chapter 10
## Taking Corrective Action

# Contents

# Taking Corrective Action

***Monitor the performance of a waste management unit and take appropriate steps to remediate any contamination. Locate and characterize source of contamination. Identify and evaluate potential corrective measures. Select and implement corrective measures to achieve attainment of cleanup standard. Work closely with the state and community representatives.***

Effective operation of a waste management unit requires checking the performance of the waste management system components. When components are not operating effectively or when a problem develops, corrective action may need to be initiated to cleanup and protect human health and the environment. Corrective action involves identifying exposure pathways of concern, selecting the best corrective measure to achieve the appropriate cleanup standard, and consulting with state and community representatives prior to beginning any extensive corrective action program.

> This chapter will help address the following questions:
>
> - What steps are associated with corrective action?
> - What information should be collected during investigations?
> - What factors should be considered in selecting an appropriate corrective measure?
> - What is involved in implementing the selected remedy?

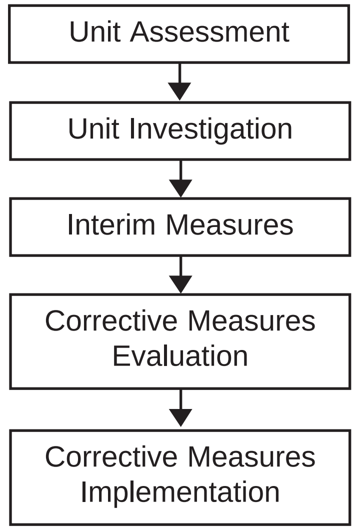
## I. Corrective Action Process

The purpose of a corrective action program is to assess the nature and extent of the releases of waste or constituents; to evaluate unit characteristics; and to identify, evaluate, and implement an appropriate corrective measure or measures to protect human health and the environment. The overall goal of any corrective action should be to perform a technically and economically feasible risk-reduction, designed to achieve a cleanup standard at a specified point on the facility property. Using the ground-water pathway as an example, corrective action for new units should have as a goal a reduction of constituent concentration levels to the ground-water protection standards, that is the maximum contaminant levels (MCLs) or health based levels, at the monitoring point.

A corrective action program generally has the components outlined below and in Figure 1. The detail required in each of these components varies depending on the unit and its complexity. Only conduct those tasks appropriate for a site, and coordinate with the state during all phases of corrective action.

- Perform a unit assessment to locate the actual or potential source(s) of the release(s) of contaminants based on the use of existing information.
- Perform a unit investigation to characterize the nature and extent of contamination from the unit and any contamination that may be migrating beyond the facility boundary; identify areas and populations threatened by releases from the unit; and determine short- and long-term threats of releases from the unit to human health and/or the environment.
- Identify, evaluate, and implement interim measures, if needed. Interim measures are short-term actions taken to protect human health and the environment while unit assessment or unit investigations are being performed or before a corrective measure is selected.
- Identify, evaluate, and implement corrective measure(s) to abate the further spread of contaminants, control the source of contamination, and to remediate releases from the unit.
- Design a program to monitor the maintenance and performance of any interim or final corrective measure(s) to ensure that human health and the environment are being protected.

Figure 1
Corrective Action Process




## A. Unit Assessment

Often the first activity in the corrective action process is the unit assessment. A unit assessment identifies potential and actual releases from the unit and makes preliminary determinations about release pathways, the need for corrective action, and interim measures. If appropriate, evaluate the possibility of addressing multiple units as the corrective action process proceeds. Table 1 identifies a number of factors to consider during a unit assessment.

As a beginning step, review all available site information regarding unit characteristics, waste characteristics, contaminant migration pathways, evidence of release, and exposure potential. Conduct a visual site inspection of the unit to confirm available information and to note any visual evidence of releases. If necessary, perform sampling to confirm or disprove suspected releases before performing an extensive unit investigation.

Table 1
Factors To Consider in Conducting a Unit Assessment

| Unit/Site Characteristics | Chemical Characteristics | Migration Pathways | Evidence of Release | Exposure Potential |
|---|---|---|---|---|
| Contamination parameters<br>—Concentrations<br>—Depth and location of contamination<br><br>Physical parameters<br>—Geology<br>—Depth to ground water<br>—Flow characteristics<br>—Climate<br><br>Historical information<br>—History of unit<br>—Knowledge of waste generation practices | Type of waste placed in the unit<br><br>Volatization parameters<br><br>Toxicological characteristics<br><br>Physical and chemical properties<br><br>Chemical class<br><br>Soil sorption/ degradation parameters | Facility's geological setting<br><br>Facility's hydogeological setting<br><br>Atmospheric conditions<br><br>Topographic characteristics | Prior inspection reports<br><br>Citizen complaints<br><br>Monitoring data<br><br>Visual evidence such as discolored soil, seepage, discolored surface water or run-off<br><br>Other physical evidence such as fish kills, worker illness, or odors<br><br>Sampling data | Proximity to affected population<br><br>Proximity to sensitive environments<br><br>Likelihood of migration to potential receptors |

Additional information on performing unit assessments can be found in *RCRA Facility Assessment Guidance* (U.S. EPA 1986).

## B. Unit Investigation

Perform a unit investigation after a release has been confirmed. The purpose of the investigation is to gather enough data to fully characterize the nature, extent, and rate of migration of contaminants to determine and support the selection of the appropriate response action. Tailor unit investigations to specific conditions and circumstances at the unit and focus on releases and potential pathways. Although each medium will require specific data and methodologies to investigate a release, a general strategy for this investigation, consisting of two elements, can be described:

- Collection and review of data such as monitoring data, data which can be gathered from outside information sources on parameters affecting the release, or the gathering of new information through such mechanisms as aerial photography or waste characterization.
- Formulation and implementation of field investigations, sampling and analysis, and/or monitoring procedures designed

to verify suspected releases, if necessary, and to evaluate the nature, extent, and rate of migration of verified releases.

Detailed knowledge of the source characteristics is valuable in identifying monitoring constituents and indicator parameters, possible release pathways, monitoring procedures, and also in linking releases to a particular unit. Waste and unit characteristics will also provide information for determining release rates and for determining the nature and scope of any corrective measures which may be applied. Refer to the characterizing waste chapter for information on how to characterize a waste.

Unit investigations may result in significant amounts of data, including results of chemical, physical, or biological analyses. This may involve analyses of many constituents, in different media, at various sampling locations, and at different times. Data management procedures should be established to effectively process these data such that relevant data descriptions, such as sample numbers, locations, procedures, and methods, are readily accessible and accurately maintained.

**Guidance on Performing Unit Investigations**

Additional guidance on performing unit inspections can be found in the following EPA documents:

- *RCRA Facility Investigation Guidance Volume 1: Development of an RFI Work Plan and General Considerations for RCRA Facility Investigations* (U.S. EPA 1989)
- *RCRA Facility Investigation Guidance Volume 2: Soil, Ground Water, and Sub-Surface Gas Releases* (U.S. EPA 1989)
- *RCRA Facility Investigation Guidance Volume 3: Air and Surface Water Releases* (U.S. EPA 1989)
- *RCRA Facility Investigation Guidance Volume 4: Case Study Examples* (U.S. EPA 1989)
- *Guidance for Conducting Remedial Investigations and Feasibility Studies Under CERCLA* (U.S. EPA 1988)
- *Draft Practical Guide for Assessing and Remediating Contaminated Sites* (U.S. EPA 1989)
- *Site Characterization for Subsurface Remediation* (U.S. EPA 1991)

## 1. Specific Considerations for Ground-Water Investigations

To facilitate ground-water investigations consider the following parameters:

- Ability of the waste to be dissolved or to appear as a distinct phase;
- Degradability of the waste and its decomposition products;
- Geologic and hydrologic factors which affect the release pathway; and
- Regional and site-specific ground-water flow regimes to determine the potential magnitude of the release pathways and possible exposure routes.

Exposure routes of concern include ingestion of ground water as drinking water and near-surface flow of contaminated ground water into basements of residences or other structures. Also address the potential for the transfer of contaminants in ground water to other environmental media such as discharge to surface water and volatilization to the atmosphere.

Use an existing ground-water monitoring program to determine the nature, extent, and rate of contaminant release from the unit(s) to the ground water. Investigation of a suspected release may be terminated based on results from an initial monitoring phase if these results show that an actual release has not, in fact, occurred. If, however, contamination is found, characterize the release through a subsequent monitoring phase(s). Subsequent characterization involves determining the detailed constituent composition and concentrations and the horizontal and vertical extent of the contaminant release, as well as its rate of migration. This should be accomplished through direct sampling and analysis and, when appropriate, can be supplemented by indirect means such as geophysical methods and modeling techniques.

## 2. Specific Considerations for Soil Investigations

When performing soil investigations, consider the following parameters:

- Ability of the waste to be dissolved by infiltrating precipitation;
- Waste's affinity for soil particles;
- Waste's degradability and its decomposition products;
- Surface features such as topography, erosion potential, land-use capability, and vegetation;
- Stratigraphic/hydrologic features such as soil profile, particle size distribution, hydraulic conductivity, pH, porosity, and cation exchange capacity; and
- Meteorological factors such as temperature, precipitation, run-off, and evapotranspiration.

Relevant physical and chemical soil properties should be measured and related to waste properties to determine potential mobility of the contaminants in the soil. Also, consider the potential for transfer of contaminants in soil to other environmental media such as overland run-off to surface water, leaching to ground water, and volatilization to the atmosphere. In addition, establish whether the release involved a localized (point) source or a non-point source. Units that are likely sources of localized releases to soil include container handling and storage areas, tanks, waste piles, and bulk chemical transfer areas. Non-point sources may include airborne particulate contamination originating from a land application unit and widespread leachate seeps from a landfill.

Table 2 presents important mechanisms of contaminant release to soils for various unit types. This information can be used to identify areas for initial soil monitoring.

## 3. Specific Considerations for Surface-Water Investigations

When conducting surface-water investigations, consider the following parameters:

- The release mechanism such as overtopping of an impoundment;

Table 2
Potential Release Mechanisms for Various Unit Types

| Unit Type | Release Mechanism |
|---|---|
| Surface impoundment | Loading and unloading areas<br>Releases from overtopping<br>Seepage |
| Landfill | Migration of releases outside the unit's run-off collection and containment systems<br>Migration of releases outside the containment area from loading and unloading operations<br>Leakage through dikes or unlined portions to surrounding soils |
| Waste pile | Migration or releases outside the unit's run-off collection and containment system<br>Migration of releases outside the containment area from loading and unloading operations<br>Seepage through underlying soils |
| Land application unit | Migration of run-off outside the application area<br>Passage of leachate into the soil horizon |

- The nature of the source area such as point or non-point;
- Waste type and degradability;
- Climatic factors such as history of floods;
- Hydrologic factors such as stream flow conditions; and

- Fate and transport factors such as the ability for a contaminant to accumulate in stream bottom sediments.

Also, address the potential for the transfer of contaminants in surface water to other environmental media such as soil contamination as a result of flooding of a contaminated creek on the facility property.

During the initial investigation particular attention should be given to sampling run-off from contaminated areas, leachate seeps, and other similar sources of surface-water contamination, as these are the primary overland release pathways for surface water. Releases to surface water via ground-water discharge should be addressed as part of the ground-water investigation for greater efficiency.

### 4. Specific Consideration for Air Release Investigations

The intent of the air release investigation is to determine actual or potential effects at a nearby receptor. Characterizing air releases may involve emission modeling to estimate unit-specific emission rates, air monitoring to determine concentrations at a nearby receptor, emission monitoring at the source to determine emission rates, and dispersion modeling to estimate concentrations at a nearby receptor. Refer to the monitoring performance chapter for more information on air monitoring and to the protecting air chapter for more information on air modeling.

As in all of the other media-specific investigations, the first step is to collect, review, and evaluate available waste, unit, environmental setting, and release data. Evaluation of these data may, at this point, clearly indicate the need for corrective measures or that no further action is required. For example, the source may involve a large, active storage surface impoundment containing volatile constituents adjacent to residential housing. Therefore, action, instead of further studies, may be appropriate. Another case may involve a unit in an isolated location, where an acceptable modeling or monitoring database indicates that the air release can be considered insignificant and therefore, further studies are not warranted. In many cases, however, further release characterization may be necessary.

## C. Interim Measures

Many cleanup programs recognize the need for interim measures while site characterization is underway or before a final remedy is selected. Typically, interim measures are used to control or abate ongoing risks before final remedy selection. Examples of interim measures for various types of waste management units and various release types are listed in Appendix I. More information is available through the *Interim Measures Guidance - Interim Final* (U.S. EPA, 1988) and *RCRA Corrective Action Stabilization Technologies* (U.S. EPA, 1992). Interim measures may be separate from the comprehensive corrective action plan, but should be consistent with and integrated with any longer term corrective measure. To the extent possible, interim measures should not seriously complicate the ultimate physical management of wastes or constituents, nor should they present or exacerbate a health or environmental threat.

## D. Evaluating Potential Corrective Measures

The corrective measure or measures selected should meet the corrective action goals, such as a state or local cleanup standard, and control or remove the source of contamination to reduce or eliminate further releases. Most corrective measures fall into one of three technology categories — containment technologies, extraction or removal technologies, or treatment technologies. Consider the performance objectives of the corrective measures in terms of source reduction, cleanup goals, and cleanup timeframe. These measures may include the repair or upgrade of existing unit components, such as liner systems, leachate

**Potential Corrective Measures**

Additional guidance on potential corrective measures is available from the following documents:

- *Corrective Action: Technologies and Applications* (U.S. EPA 1989)
- *Handbook: Stabilization Technologies for RCRA Corrective Actions* (U.S. EPA 1991)
- *RCRA Corrective Action Stabilization Technologies* (U.S. EPA 1992)
- *Pump and Treat Ground-Water Remediation: A Guide for Decision Makers and Practitioners* (U.S. EPA 1996)
- *Handbook: Remediation of Contaminated Sediments* (U.S. EPA 1991)
- *Abstracts of Remediation Case Studies* (U.S. EPA 1995)
- *Bioremediation Resource Guide* (U.S. EPA 1993)
- *Groundwater Treatment Technology Resource Guide* (U.S.EPA 1994)
- *Physical/Chemical Treatment Technology Resource Guide* (U.S.EPA 1994)
- *Soil Vapor Extraction Treatment Technology Resource Guide* (U.S.EPA 1994)

collection systems, or covers. Base corrective measure(s) selection on the following considerations and contact the state and community representatives before finalizing the selection:

- The ability to meet cleanup standards;
- The appropriateness and effectiveness of the treatment technology in relation to the waste and site characterizations;
- The long- and short-term effectiveness including economical and technical feasibility and protectiveness of the remedy;
- The effectiveness of the remedy in controlling the source to reduce further releases;
- The ease of implementing the remedy; and
- The degree to which local community concerns have been addressed.

## 1. Meeting Cleanup Standards

Work with the state and community representatives to establish risk-based cleanup standards for the media of concern (ground water, surface water, soil, air) before identifying potential corrective measures. For example, if there is a statistically significant increase of constituent concentrations over background in the ground water, cleanup standards would include reducing contaminant concentrations to the MCL or health-based level at the point of monitoring.

Several approaches have been developed to identify appropriate cleanup standards. One of the more recent approaches is the Risk-Based Corrective Action (RBCA) standard developed by some states and the American Society for Testing and Materials (ASTM) Committee. The RBCA standard provides guidance on how to integrate ecological and human health risk-based decision-making into the traditional corrective action process described above. RBCA is a decision-making process for the assessment and response to chemical releases. This standard is applicable to all types of chemical release sites, which may vary greatly in terms of their complexity, physical and chemical characteristics, and the risk they pose to human health and the environment. RBCA uses a tiered approach that begins with simple analyses and moves to more complex evaluations when necessary. The foundation of the RBCA process is that technical policy decisions are identified in the front-end of the process to ensure that data collected are of sufficient quantity and quality to answer questions posed at each tier of the investigation. The RBCA standard is not intended to replace existing regulatory programs, but rather to provide an enhancement to these programs. The RBCA process allows for a three-tiered approach as described below. More information on RBCA is available from ASTM's *Draft Standard Guide for Risk-Based Corrective Action*, and a 1997 draft report prepared by the Louisiana Department of Environmental Quality, *Proposed Louisiana Department of Environmental Quality Risk-Based Corrective Action Program.* Consult with the state and community representatives to determine the appropriateness of a RBCA approach.

### Tier 1 Evaluation

A Tier 1 evaluation classifies a site according to the urgency for corrective action using broad measures of release and exposure. This tier is used to identify the source(s) of the chemical release, obvious environmental impacts, potential receptors, and significant exposure pathways. During a Tier 1 evaluation, site-specific contaminant concentrations are compared against a standard table of risk-based screening levels (RBSLs) that have been developed using conservative, nonsite-specific exposure assumptions. If site contaminant concentrations are found to be above the RBSLs, then corrective action or further evaluation would be considered. Continued monitoring may be the only requirement if site-specific contaminant concentrations are below the RBSLs. Hence, at the end of the Tier 1 evaluation, initial corrective action responses are selected while additional analysis is conducted to determine final remedial action, if necessary. The standard includes an exposure scenario evaluation flowchart to help identify appropriate receptors and exposure scenarios based on current and projected reasonable land use scenarios, and appropriate response actions.

Site conditions should also be compared to relevant ecological screening criteria (RESC) applicable to the site which might include qualitative or quantitative benchmarks, comparison of site conditions to local biological and environmental conditions, or considerations related to the exposed habitat areas.

### Tier 2 Evaluation

The user may decide to conduct a Tier 2 evaluation after selecting and implementing the appropriate initial response action to the Tier 1 evaluation. The purpose of this tier is to determine site-specific target levels (SSTLs) and appropriate points of compliance when it is determined that Tier 1 RBSLs are not appropriate. While a Tier 2 evaluation is based on similar screening levels as those used in the Tier 1 evaluation, some of the generic assumptions used in the earlier evaluation are replaced with site-specific measurements to develop the SSTLs. The intent of Tier 2 is to incorporate the concept that measured levels of contamination may decline over the distance from source to receptor. Thus, simple environmental fate and transport modeling is used to predict attenuation over that distance. If site-specific contaminant concentrations are above the SSTLs, corrective action is needed and further analysis may be required.

### Tier 3 Evaluation

A Tier 3 evaluation involves the same steps as those taken during the Tier 1 and Tier 2 evaluations, except that a significant increase in effort is employed to refine and better define the scope of the contamination. Actual levels of contamination are compared to

SSTLs that are developed for this Tier. The Tier 3 SSTLs differ from Tier 2 SSTLs in the level of sophistication used to develop site-specific measures of environmental fate and transport of contaminants. Where simplified, site-specific measures of environmental fate and transport are used in the Tier 2 evaluation, much more sophisticated models will be used in this Tier. These models may rely on probabilistic approaches and on alternative toxicity and biodegradability data.

## 2. Evaluating Treatment Technologies

In nearly every phase of the corrective action process, some information about treatment technologies is needed. Many documents exist that describe candidate technologies in detail and give their respective applicability and limitations. Below are descriptions and examples of the three major treatment technology categories.

Containment technologies are used to stop the further spread or migration of contaminants. Some examples of common containment techniques for constituents in land-based units include waste stabilization, solidification, and capping. Capping and other surface-water diversion techniques, for instance, can control infiltration of rainwater to the contaminated medium. Typical ways to contain contaminated ground-water plumes include ground-water pumping, subsurface drains, and barrier or slurry walls. These ground-water containment technologies control the migration of contaminants in the ground-water plume and prevent further dissolution of contaminants by water entering the unit. Each of these ground-water containment technologies is briefly described in Appendix II.

Extraction or removal technologies physically remove constituents from a site.

Extraction techniques may remove the constituent of concern only, or the contaminated media itself. For example, vapor extraction may just remove the constituent vapors from the soil, while excavation would remove all of the contaminated soil. Extraction technologies include excavation, pumping, product recovery, vapor extraction or recovery, and soil washing.

Treatment or destruction technologies render constituents less harmful through biological, chemical, and thermal techniques. Some examples are ground-water treatment, pH adjustment, oxidation and reduction, bioremediation, and incineration. A broader perspective on ground-water, chemical, biological, thermal, and stabilization treatment technologies is presented in Appendix III.

In selecting a treatment technology or set of technologies, it is important to consider the information obtained from the waste and site characterization. For example, the waste characterization should tell the location of the waste and in what phases the waste should be expected to be found, such as sorbed to soil particles. Waste characterization information also allows for the assessment of the leaching characteristics of the waste, its ability to be degraded, and its tendency to react with chemicals. The site characterization information will reveal important information about subsurface flow conditions and other physical characteristics (such as organic carbon content). Use the information from the

[1]U.S. EPA, 1991. *Site Characterization for Subsurface Remediations*

Figure 2

Screening Process for Selecting Appropriate Treatment Technologies

Evaluate waste and site-specific information and identify potential treatment technologies

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Develop a conceptual design for each technology including:
- Process description
- Process flow diagram
- Layout drawing
- Preliminary sizing of equipment, utility, and land requirements
- Chemical requirements
- Expected residuals

↓

Compare technologies using:
- Effectiveness and reliability of technology meeting cleanup goals
- Beneficial and adverse effects on the environment
- Beneficial and adverse effects on human health
- Ability to meet federal, state, and local government standards and gain public acceptance
- Capital, operating, and maintenance costs

↓

Select most appropriate technology in consultation with state and community representatives

↓

Obtain state approval

waste and site characterization to select the appropriate treatment technology. In some cases, a treatment train, a series of technologies combined together, will be appropriate.[1] A screening process for selecting an appropriate technology is presented in Figure 2. This step-by-step approach will help ensure that technologies that may be applicable at a site are not overlooked. In addition, the rationale for the elimination of specific technologies will be available to justify decisions to interested parties.

Additional information regarding the use and development of innovative treatment technologies is available from the Federal Remediation Technologies Roundtable's web site at <http://Solaris.frtr.gov>. In cooperation with the Federal Remediation Technologies Roundtable, the Army Environmental Center has developed the document *Remediation Technologies Screening Matrix and Reference Guide, Version 3.0.* This guide contains a screening matrix for evaluating treatment technologies. A copy of this matrix is attached as Appendix IV.

## 3. Evaluating the Long- and Short-Term Effectiveness of the Remedy

To evaluate the long- and short-term effectiveness of the remedy, analyze the risks associated with the remedy as those risks pertain to the construction and implementation of the corrective measure. Because waste characteristics vary from site to site, the effect of a treatment technology with a particular waste may be unknown. Consider, therefore, performing a treatability study to evaluate the effectiveness of one or more potential remedies. Spending the time and money up-front to better assess the effectiveness of a technology on a waste can save significant time and money later in the process. To judge the technical certainty that the remedy will attain the corrective action goal, also consider reviewing case studies where similar technologies have been applied.

Invest a reasonable amount of effort to estimate and quantify risks, based on exposure pathways, estimates of exposure levels, and duration of exposure at a site. It is also important to analyze the time to complete the

**Treatability Studies**

The four general types of treatability studies are laboratory-scale, bench-scale, pilot-scale, and field-scale.

- **Laboratory-scale** studies are small scale screening studies that generate qualitative information concerning the general validity of a treatment approach.
- **Bench-scale** studies are intermediate studies conducted in the laboratory. Bench scale studies are intended to answer specific, design, operation, and cost questions, and are more detailed than laboratory studies.
- **Pilot-scale** studies are large scale experiments intended to provide quantative cost and design data. They simulate anticipated full-scale operational configurations as closely as possible.
- **Field-scale** studies are large scale studies intended to monitor the performance of treatment systems under real world conditions at close to full scale operations

More information on treatability studies can be found in *A Guide for Conducting Treatability Studies Under CERCLA* (U.S. EPA, 1992).

corrective measure, because it directly impacts the cost of the remedy. Carefully evaluate the long-term costs of the remedial alternatives and the long-term financial condition of the facility. Consider including quality control measures in the implementation schedule to assess the progress of the corrective measure. It is also important to determine the degree to which the remedy complies with all applicable state laws.

## 4. Evaluating the Effectiveness of Reducing or Eliminating the Source of Contamination

There are two major components of source control that should be evaluated. First, if source control consists of the removal, redisposal, or treatment of wastes and the residual materials, such as contaminated soils, the volume of wastes and residual materials should be quantified and the potential to cause further contamination evaluated. Second, engineering controls intended to upgrade or repair deficient conditions at a waste management unit should be quantified in terms of anticipated effectiveness according to current and future conditions. This evaluation should determine what is technically and financially practicable. Health considerations and the potential for unacceptable exposure(s) to both workers and the public may affect an evaluation.

## 5. Evaluating the Ease of Implementation

The ease of implementing the proposed corrective measure will affect its schedule. To evaluate the ease of implementation of a specific corrective measure, consider the availability of technical expertise, the construction of equipment or technology, the ability to properly manage, dispose, or treat wastes generated by the corrective measure, and the likelihood of obtaining local permits and public acceptance for the remedy. Consider also the potential for contamination to transfer from one media to another as part of the overall feasibility of the remedy. Cross-media impacts should be addressed as part of the implementation phase. Develop a corrective measure schedule identifying the start and end points of the permitting phase, the construction and startup period, the time when full-scale treatment will be initiated and the duration of the treatment period, and the implementation and completion of source control measures.

### 6. Measuring the Degree to Which Community Concerns are Met

Prior to selecting the corrective measure(s), hold a public meeting to discuss the results of the corrective action assessment and to identify proposed remedies. Consider notifying adjacent property owners via mail of any identified contamination and proposed remedies. Identify any public concerns that have been expressed, via written public comments or from public meetings, about the facility's contamination and ensure that these concerns are adequately addressed by the corrective measures being evaluated. The best remedy selected and implemented will be one that is agreed upon by the state or local regulatory agency, the public, and the facility owner. Review the information presented in the building partnerships chapter before selecting any final remedies.

## E. Implementing Corrective Measures

Implementation of the corrective measures encompass all activities necessary to initiate and continue remediation. During the evaluation and assessment of the nature and extent of the contamination, decide whether no further assessment is necessary, whether institutional controls are necessary to protect human health and the environment, whether monitoring and site maintenance is necessary, and whether no further action and closure are appropriate actions for the unit.

**Citizen Guides to Treatment Technologies**

EPA's Technology Innovation Office has developed a series of fact sheets that explain, in basic terms, the operation and application of innovative treatment technologies for remediating sites. The fact sheets address issues associated with innovative treatment technologies as a whole, bioremediation, chemical dehalogenation, in situ soil flushing, natural attenuation, phytoremediation, soil vapor extraction and air sparging, soil washing, solvent extraction, thermal desorption, and the use of treatment walls. A copy of *A Citizen's Guide to Innovative Treatment Technologies* is attached as Appendix V.

English and Spanish versions of the fact sheets can be downloaded from the Internet at **<http://clu-in.com/citguide>**.

### 1. Institutional Controls

Institutional controls are those controls that can be utilized by responsible parties and regulatory agencies in remedial programs where, as part of the program, certain levels of contamination will remain on site in the soil or ground water. Institutional controls can also be considered in situations where there is an immediate threat to human health. Institutional controls may vary in both form and content. Agencies and landowners can invoke various authorities and enforcement mechanisms, both public and private, to implement one or more of the controls. A state could adopt a statutory mandate, for example, requiring the use of deed restrictions as a way of enforcing use restrictions and posting signs. Commonly used institutional controls include the following:

- Deed restrictions, or restrictive covenants;
- Use restrictions (including all restriction areas);

**Selecting a Corrective Action Specialist**

Once it has been determined that corrective measures are necessary, determine if in-house expertise is adequate or if an outside consultant is necessary.

If a consultant is needed, determine if the prospective company has the technical competence to do the work needed. A poor design for a recovery system, unacceptable field procedures, lack of familiarity with state requirements, or an inadequate investigation may unnecessarily cost thousands of dollars and still not complete the cleanup.

Some of the most important information to consider in selecting a consultant is whether the company has experience performing site investigations and remediations at similar sites, is familiar with state regulations, has staff trained in the use of field screening instruments, has experience in monitoring well design and installations, has established quality assurance and quality control procedures, and can provide references.

- Access controls;
- Notices, including record notice, actual notice, and notice to government authorities;
- Registry act requirements;
- Transfer act requirements; and
- Contractual obligations.

A brief description of these institutional controls is presented in Appendix VI.

## 2. Monitoring and Site Maintenance

In many cases, monitoring may need to be conducted to demonstrate the effectiveness of the implemented corrective measures. Consult with the state to determine the amount of time that monitoring should be conducted. Some corrective measures, such as capping, hydraulic control, and other physical barriers, may require long-term maintenance to ensure integrity and continued performance. Upon completion and verification of cleanup goals reinstitute the original or modified ground-water monitoring program if the unit is still in active use.

## 3. No Further Action and Site Closure

When the corrective action goals have been achieved, and monitoring and site maintenance are no longer necessary to ensure that this condition persists, reinstitute the original or modified ground-water monitoring program if the unit is still in active use. It may be necessary, however, to ensure that any selected institutional controls remain in place. Refer to the chapter on performing closure and post-closure care for additional information.

## Corrective Action Action Items

Consider the following when developing a corrective action program for nonhazardous industrial solid waste management units:

- ❑ Locate the source(s) of the release(s) of contaminants and determine the extent of the contamination.
- ❑ Consult with the state, community representatives, and qualified remedial experts when developing a corrective action program.
- ❑ Identify and evaluate all potential corrective measures including interim measures.
- ❑ Select and implement corrective measures based on the effectiveness and protectiveness of the remedy, the certainty that the remedy will achieve established goals, the ease of implementing the remedy, and the degree that the remedy meets local community concerns and all applicable state laws.
- ❑ Design a program to monitor the maintenance and performance of corrective measures to ensure that human health and the environment are being protected.

## Resources

ASTM. 1997. Standard guide for risk-based corrective action. Draft. February.

ASTM. 1994. Emergency standard guide for risk-based corrective action applied at petroleum release sites. May.

Louisiana Department of Environmental Quality. 1997. Draft report: Proposed Louisiana Department of Environmental Quality risk-based corrective action program. March.

Texas Natural Resource Conservation Commission (TNRCC). 1995. TNRCC technical guidance: Selecting an environmental consultant/corrective action specialist. February.

U.S. EPA. 1996. A citizen's guide to innovative treatment technologies. EPA542-F-96-001.

U.S. EPA. 1996. Corrective action for releases from solid waste management units at hazardous waste management facilities: Advance notice of proposed rulemaking. Fed. Reg. 61(85): 19,431-19,464. May 1.

U.S. EPA. 1996. Pump-and-treat ground-water remediation: A guide for decision-makers and practitioners. EPA625-R-95-005.

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# Part 5
# Ensuring Long-Term Protection

## Chapter 11
## Performing Closure and Post-Closure Care

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# Performing Closure and Post-Closure Care

*Providing closure and post-closure care is an integral part of a unit's overall design and operation, helping to reduce or eliminate potential threats and the need for future corrective action at the site. Planning and accomplishing the goals of closure and post-closure care require adequate funding be set aside to cover the planned costs of such activities.*

The overall goal of closure is to minimize or eliminate potential threats and the need for future corrective action at the site. If removing the wastes, containment devices, and any contaminated subsoils from a unit, the unit should be returned to an acceptable risk level, so that the unit is not a current or future threat to human health and the environment. If wastes will be left in place at closure, the unit should be closed in a manner to reduce and control current or future threats to human health and the environment. Also, avoid future disruptions to final cover systems and monitoring devices.

This chapter will help address the following questions:

- How do I develop a closure plan?
- What factors should I consider when choosing a closure method?
- What are the components of a final cover?
- What costs are associated with post-closure care?

For post-closure care, the overall goal is to minimize the infiltration of water into a unit by providing maintenance of the final cover until such time as it is determined that care is no longer necessary. Also, during post-closure care closed units should be monitored to verify and document that unacceptable releases are not occurring.

## I. Closure Plans

A well-conceived closure plan is the primary resource document for the final stage in the life of a waste management unit. The purpose of a closure plan is to consider all aspects of the closure scenario. It should be comprehensive so that staff who will implement it years after its writing will clearly understand the activities it specifies. It also needs to be sufficiently detailed in order to calculate the costs of closure and post-closure care for purposes of determining how much funding needs to be set aside for those activities.

## What should I consider when developing a closure plan?

Tailor a closure plan to account for the unique characteristics of the unit, the waste managed in the unit, and anticipated future land use. Each unit will have different closure activities. Closing a surface impoundment, for example, involves removal of remaining liquids and solidifying sludges prior to placing a final cover on the unit.

Consider the following information when developing a closure plan:

- Overall goals and objectives of closure;
- Future land use;
- Type of waste management unit;
- Types, amount, and physical state of waste in the unit;
- Constituents associated with the wastes;
- Whether wastes will be removed or left in place at closure;
- Schedule (overall and interim);
- Costs to implement closure;
- Steps to monitor progress of closure actions, including inspections, maintenance activities, and necessary monitoring (e.g., ground-water and leachate monitoring) where appropriate;
- Revisions to health and safety plan, as necessary;
- Contingency plans;
- Description of waste treatment or stabilization (if applicable);
- Final cover information (if applicable);
- Waste removal information (if applicable); and
- Parameters to assess performance of the unit throughout the post-closure period.

The plan should address the types of waste that have been or are expected to be deposited in the management unit and the constituents that can reasonably be associated with those wastes. The types of expected wastes will affect both the design of the final cover and the types of activities that should be undertaken during the post-closure care period. Biodegradable waste, for example, may cause a final cover to subside due to decomposition and may also require gas management.

The closure plan should provide other information that will address the closure strategy. If, for instance, a final cover is planned, then the closure plan will need to consider seasonal precipitation that could influence the performance of both the cover and the monitoring system. Information concerning freeze cycles and the depth of frost permeation will provide supporting information with which to assess the adequacy of the cover design. Similarly, arid conditions should be addressed to support a decision to use a particular cover material, such as cobbles.

The closure plan should address the closure schedule, stating the dates when waste will initially be placed in a unit, when closure will begin, and when closure is expected to be completed. Consider starting closure when the unit has reached capacity or has received the last expected waste for disposal. For units containing inorganic wastes, complete closure as soon as possible after the last expected waste has been received. A period of 180 days is a good general guide for completing closure, but the actual time frame will be dictated by site-specific conditions. For units receiving organic wastes, more time may be needed for the wastes to stabilize prior to completing closure. Similarly, other site-specific conditions, such as precipitation or winter weather, may also cause delay in completing closure. For these situations, complete closure as soon as feasible. Consult with the state agency to determine if requirements exist for closure schedules.

Even within a waste management unit, some areas will be closed on different schedules, with certain areas in partial closure, while other areas continue to operate. The schedules and partial closure activities (such as intermediate cover) should be considered in the closure plan. Although the processes for closing such areas may not be different than those for closing the unit as a whole, it is still more efficient to integrate partial closure activities into the closure plan.

If the closure plan calls for the stabilization, solidification, or other treatment of wastes in the unit before the installation of a final cover, the plan should describe those activities in detail. Waste stabilization, solidification, or other treatment has four goals:

- Remove liquids, which are ill-suited to supporting the final cover;
- Decrease the surface area over which the transfer or escape of contaminants can occur;
- Limit the solubility of leachable constituents in the waste; and
- Reduce toxicity of the waste.

For closure strategies that will use engineering controls, such as final covers, the plan should provide detailed specifications, including descriptions of the cover materials in each layer and their permeability as well as any drainage and/or gas migration control measures included in the operation of the final cover. Also identify measures to verify the continued integrity of the final cover and the proper operation of the gas migration and/or drainage control strategies.

If wastes will be removed at closure, the closure plan should estimate volumes of waste and contaminated subsoil and the extent of contaminated devices to be removed during closure. It should further state waste removal procedures, establish performance goals, and address any state or local requirements for closure by waste removal. The plan should identify numeric clean-up standards and existing background concentrations of constituents. It also should discuss the sampling plan for determining the effectiveness of closure activities. Finally, it should describe the provisions made for the disposal of removed wastes and other materials.

The closure plan should also provide a detailed description of the monitoring that will be conducted to assess the performance of the waste management unit throughout the post-closure period. These measurements include monitoring leachate volume and characteristics to ensure that a cover is minimizing infiltration. It is important to include appropriate ground-water quality standards with which to compare ground-water monitoring reports. The performance measures section of the plan establishes, prior to completing closure, the parameters that will describe successful closure of the unit. If limits on these parameters are exceeded, it will provide an early warning that the final cover system is not functioning as designed and that measure should be undertaken to identify and correct problems.

# II. Selecting a Closure Method

Factors to consider in deciding whether to perform closure by means of waste removal or through the use of a final cover include the following:

- **Feasibility.** Is closure by waste removal feasible? For example, if the waste volumes are large and underlying soil and ground water are contaminated, closure by total waste removal may not be possible. If the unit is contaminated, consult the chapter on taking corrective action to identify activities to address the contamination. In some cases, even in situations where contamination is a concern, partial removal of the waste may be useful to remove the source of ground-water contamination.

- **Cost-effectiveness.** Compare the costs of removing waste, containment devices, and contaminated soils, plus subsequent disposal costs at another facility, to the costs of installing a final cover and providing post-closure care.
- **Long-term protection.** Will the final cover control, minimize, or eliminate, to the extent necessary to protect human health and the environment, post-closure escape of waste constituents or contaminated run-off to ground or surface waters?
- **Availability of alternate site.** Is an alternate site available for final disposal or treatment of removed waste? Consult with the state agency to determine whether alternate disposal sites are appropriate.

# III. Closure by Use of Final Cover Systems

You may elect to close a waste management unit by means of a final cover system. This approach is common for landfill units and some surface impoundment units where some waste is left in place. The choice of final cover materials and design should be the result of a careful review and consideration of all site-specific conditions that will affect the performance of the cover system. If you are not knowledgeable about the engineering properties of cover materials, seek the advice of professionals or representatives of state and local environmental protection agencies.

This section will discuss the more important technical issues that should be considered when selecting cover materials and designing a cover system. It will also discuss the various potential components of final cover systems, discussing the types of materials that can be used in their design and some of the advantages and disadvantages of each. Throughout the section, the interaction between the various components as they function within the system will be discussed.

## A. Purpose and Goal of Final Cover Systems

The principal goals of final cover systems are to:

- Protect human health and the environment by reducing or eliminating potential risk of contaminant release;
- Minimize infiltration of precipitation into the waste management unit to minimize generation of leachates within the unit by promoting surface drainage and maximizing run-off;
- Minimize risk by controlling gas migration, and by providing physical separation between waste and humans, plants, and animals; and
- Minimize long-term maintenance needs.

For optimal performance, the final cover system should be designed to minimize permeability, surface ponding, and the erosion of cover material. To avoid the accumulation of leachate within a unit, the cover system should be no more permeable than the liner system. For example, if a unit's bottom liner system is composed of a low-permeability material, such as compacted clay or a geomembrane, then the cover should also be composed of a low-permeability material unless an evaluation of site-specific conditions shows an equivalent reduction in infiltration.

If the cover system is more permeable than the liner, leachate will accumulate in the unit, since infiltration through the cover will exceed leachate exfiltration through the liner system. This buildup of liquids within a unit is often referred to as the "bathtub effect." In addition, since many units can potentially generate gas, cover systems should be designed to control gas migration. It is essential to ensure proper quality assurance and quality control during construction and installation of the final cover so that the final cover performs in accordance with its design. For general information on quality assurance during construction of the final cover, consult the construction quality assurance section of the chapter on designing and installing liners. Recommendations for the type of final cover system to use will depend on the type of liner and the gas and liquids management strategy employed in a unit.

## B. Technical Considerations for Selecting Cover Materials

Several environmental and engineering concerns can affect cover materials and should be considered in the choice of those materials.

### How can climate affect a final cover?

Freeze and thaw effects can lead to the development of microfractures in low permeability soil layers. These effects also can cause the realignment of interstitial fines (silts and clays), thereby increasing the hydraulic conductivity of the final cover. As a result, determine the maximum depth of frost penetration at a site and design covers accordingly (in other words, ensure barrier layers are below the maximum frost penetration depth). Information regarding the maximum frost penetration depth for a particular area can be obtained from the Natural Resource Conservation Service with the U.S. Department of Agriculture, local utilities, construction companies, local universities, or state agencies. Figure 1 illustrates the regional depth of frost penetration. Ensure that vegetation layers are thick enough to ensure that any geomembrane and the low permeability soil layers in the final cover are placed below the maximum frost penetration depth.

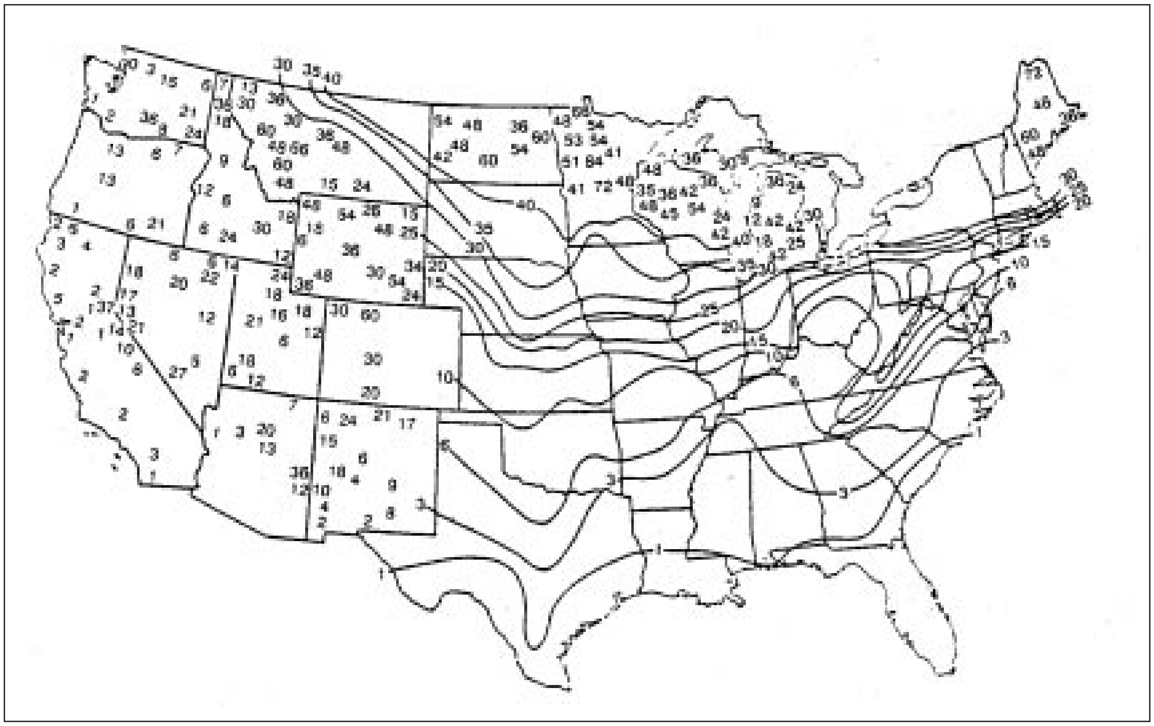
### How can settlement and subsidence affect a final cover?

When waste consolidates, settlement and subsidence can result. Excessive settlement and subsidence can significantly impair the integrity of the final cover system by causing ponding of water on the surface, fracturing of low permeability infiltration layers, and failure of geomembranes. The degree and rate of waste settlement are difficult to estimate; however many industrial solid wastes decompose at such a slow rate that settlement is minimal.

### How can erosion affect the performance of a final cover?

Erosion can adversely affect the performance of the final cover of a unit by causing rills that require maintenance and repair. Extreme erosion may lead to the exposure of the infiltration layer, initiate or contribute to sliding failures, or expose the waste. Anticipated erosion due to surface-water runoff for a given design criteria may be approximated using the USDA Universal Soil Loss Equation (U.S. EPA 1989a). By evaluating erosion loss, you may be able to optimize the final cover design to reduce maintenance through selection of the best available soil materials. A vegetative cover not only

**Figure 1. Regional Depth of Frost Penetration in Inches**



Source: U.S. EPA. 1989a. Seminar publication: Requirements for hazardous waste landfill design, construction and closure.

improves the appearance of a unit, but it also controls erosion of the final cover. The vegetation components of the erosion layer should have the following characteristics:

- Locally adapted perennial plants that are resistant to various climatic changes reasonably expected to occur at the site;
- Roots that will not disrupt the low-permeability layer;
- The ability to thrive in low-nutrient soil with minimum nutrient addition; and
- The ability to survive and function with little or no maintenance.

## Why are interfacial and internal friction properties for cover components important?

Adequate friction between cover components, such as geomembrane barrier layers and soil drainage layers, as well as between any geosynthetic components, is required to prevent extensive slippage or interfacial shear. Water and ice may affect the potential for cover components to slip. Sudden sliding can tear geomembranes or cause sloughing of earthen materials. Internal shear may also be a concern for composite or geosynthetic clay liner materials. Measures to improve stability include using flatter slopes or textured geosynthetic membranes, geogrids designed to resist slipping forces, or otherwise reinforcing the cover soil.

## Can dry soil materials affect a final cover?

Desiccation, the natural drying of soil materials, may have an adverse affect on the soil layers, compromising the final cover. Although this process is most commonly associated with layers of low permeability soil, such as clay, it can cause problems with other soil types as well. Desiccation causes cracks in the soil surface extending downward. Cover layers are not very thick, and therefore, these cracks can extend through an entire layer, radically changing its hydraulic conductivity or permeability. Care should be taken to detect desiccation at an early stage in time to mitigate its damage. Also, the tendency for final covers to become dry makes root penetration even more of a problem in that plants respond to drought by extending their root systems downward.

## Can plants and animals have an effect on a final cover?

When selecting the plant species to include in the vegetative cover of a waste management unit, consider the potential for root systems to grow through surface cover layers and penetrate underlying barrier layers. Such penetration will form preferential pathways for water infiltration and compromise the integrity of the final cover system. Similarly, the presence of burrowing animals should be foreseen when designing the final cover system. Such animals may burrow in the surface layers and can potentially breach the underlying barrier layer. Strategies for mitigating the effects described here are discussed below in the context of protection layers composed of gravel or cobbles.

## Is it necessary to stabilize wastes?

Before installing a final cover, liquid or semi-liquid wastes may need to be stabilized or solidified. Stabilization or solidification may be necessary to allow equipment on the unit to install the final cover and/or to ensure adequate support, or bearing capacity, for the final cover. With proper bulk cover technique, it may be feasible to place the cover over a homogeneous gel-like semi-liquid waste. When selecting a stabilization or solidification process, consider the effectiveness of the process and its compatibility with the wastes. Performance specifications for stabilization or solidification processes include leachability, free-liquid content, physical stability, bearing capacity, reactivity, ignitability, biodegradability, strength, permeability, and durability of the stabilized and solidified waste. Consider seeking professional assistance to properly stabilize or solidify waste prior to closure.

Where solidification is not practical, consider construction of a specialized lighter weight cover system over unstable wastes. This involves using geogrids, geotextiles, geonets, geosynthetic clay liners, and geomembranes, in conjunction with each other. For more detail on this practice, consult the paper by Robert P. Grefe, *Closure of Papermill Sludge Lagoons Using Geosynthetics and Subsequent Performance*, and the Geosynthetic Research Institute Proceedings, *Landfill Closures: Geosynthetics Interface Friction and New Developments*, cited in the Resources section.

## How can I stabilize wastes?

Many stabilization and solidification processes require the mixing of waste with other materials, such as clay, lime, and ash. These processes include either sorbents or encapsulating agents. Sorbents are nonreactive and nonbiodegradable materials that soak up free liquids to form a solid or near-solid mass. Encapsulating agents enclose wastes to form an impermeable mass. The following are examples of some commonly used types of waste stabilization and solidification methods.

- **Cement-based techniques.** Portland cement can use moisture from the waste (sludge) for cement hydration. The end product has high strength, good durability, and retains waste effectively.
- **Fly ash or lime techniques.** A combination of pozzolanic fly ash, lime, and moisture can form compounds that have cement-like properties.
- **Thermoplastic techniques.** Asphalt, tar, polyolefins, and epoxies may be mixed with waste, forming a semirigid solid after cooling.
- **Organic polymer processes.** This technique involves adding and mixing monomer with a sludge, followed by adding a polymerizing catalyst. This technique entraps the solid particles.

After evaluating and selecting a stabilization or solidification process, conduct pilot-scale tests to address issues such as safety, mix ratios, mix times, and pumping problems. Testing will help assess the potential for an increase in waste volume. It will also help to plan the production phase, train operators, and devise construction specifications.

When conducting full-scale treatment operations, options exist for adding and mixing materials. These options may include in-situ mixing and mobile plant mixing. In-situ mixing is the simplest technique, using common construction equipment, such as backhoes, excavators, and dump trucks. In-situ mixing is most suitable where large amounts of materials are added to stabilize or solidify the waste. The existing waste management area, such as a surface impoundment, can be used as the mixing area. The in-situ mixing process is open to the atmosphere, so environmental and safety issues, such as odor, dust, and vapor generation, should be taken into consideration. For mobile plant mixing, wastes are removed from the unit, mechanically mixed with treatment materials in a portable processing vessel, and deposited back into the unit. Mobile plant mixing is generally used for treating sludges and other wastes with a high liquid content.

## C. Components of a Final Cover

Cover systems can be designed in a variety of ways to accomplish closure goals. This flexibility allows a final cover design system to integrate site-specific technical considerations that may affect performance. This section discusses the potential components or layers of a final cover system, their functions, and appropriate materials for each layer. Since the materials used in cover systems are the same as those used in liner systems, refer to the chapter on designing and installing liners for a more detailed discussion of the engineering properties of the various materials. Table 1 presents the types of layers and typical materials that may exist in a final cover. The minimum appropriate thicknesses of each of the five types of layers depends upon many factors including site drainage, erosion potential, slopes, types of vegetative cover, type of soil, and climate.

### What function does the surface layer serve?

The role of the surface layer in the final cover system is to promote the growth of native, nonwoody plant species, minimize erosion, restore the aesthetics of the site, and

Table 1
Types of layers in Final Cover Systems

| Layer | Type of Layer | Typical Materials |
|---|---|---|
| 1 | Surface (Erosion, Vegetative Cover) Layer | Topsoil, Geosynthetic Erosion Control Layer, Cobbles |
| 2 | Protection Layer | Soil, Recycled or Reused Waste Materials, Cobbles |
| 3 | Drainage Layer | Sand and Gravel; Geonet or Geocomposite; Chipped or Shredded Tires |
| 4 | Barrier (Infiltration) Layer | Compacted Clay, Geomembrane, Geosynthetic Clay Liner |
| 5 | Foundation/Gas Collection Layer | Sand or Gravel, Soil, Geonet or Geotextile, Recycled or Reused Waste Material |

protect the barrier layer. The surface layer should be thick enough so that the root systems of the plants do not penetrate the underlying barrier layer. The vegetation on the surface layer should be resistant to drought and temperature extremes, able to survive and function with little maintenance, and also be able to maximize evapotranspiration, which will limit water infiltration to the barrier layer. Consult with agriculture or soil conservation experts concerning appropriate cover vegetation. Finally, the surface layer should be thick enough to withstand long-term erosion and to prevent desiccation and freeze/thaw effects of the barrier layer. The recommended thickness for the surface layer is at least 12 inches. Consult with the state agency to determine the appropriate minimum thickness in cold climates to protect against freeze-thaw effects.

## What types of materials can be used in the surface layer?

**Topsoil** has been by far the most commonly used material for surface layers. The principal advantages of using topsoil in the surface layer include its general availability and its suitability for sustaining vegetation. When topsoil is used as a surface layer, the roots of plants will reinforce the soil, reduce the rate of erosion, decrease run-off, and remove water from the soil through evapotranspiration. If topsoil is to be used in the surface layer, the soil should have sufficient water-holding capacity to sustain plant growth. There are some concerns with regard to using topsoil. For example, topsoil requires ongoing maintenance, especially during periods of drought or heavy rainfall. Prolonged drought can lead to cracking in the soil, creating preferential pathways for water infiltration. Heavy rainfall can lead to erosion causing rills or gullies, especially on newly-seeded or steeply sloping covers. If the topsoil does not have sufficient water holding capacity, it may not adequately support surface plant growth, and evapotranspiration may excessively dry the soils. In this case, irrigation may be required to restore the water balance within the soil structure. Topsoil is also vulnerable to penetration by burrowing animals.

**Geosynthetic erosion control material** can be used as a cover above the topsoil to limit erosion prior to the establishment of a mature vegetative cover. The geosynthetic material can include embedded seeds to promote plant growth, while minimizing soil run-off. It can be anchored or reinforced to add stability on steeply sloped covers. Geosynthetic material, however, does not enhance the water-holding capacity of the soil. In arid or semi-arid areas, therefore, the soil may still be prone to wind and water erosion if its water-holding capacity is insufficient.

**Cobbles** may be a suitable material for the surface layer in arid areas or on steep slopes which might hinder the establishment of vegetation. If they are large enough they will provide protection from wind and water erosion without washout. Cobbles can also protect the underlying barrier layer from intrusion by burrowing animals, but cobbles may not be available locally, and their use does not protect the underlying barrier layer from water infiltration. Because cobbles create a porous surface through which water can percolate, they do not ordinarily support vegetation. Wind-blown soil material can fill voids between cobbles, and plants may establish themselves in these materials. This plant material should be removed, as its roots are likely to extend into the underlying barrier layer in search of water.

## What function does the protection or biotic barrier layer serve?

A protection or biotic barrier layer may be added below the surface layer, but above the drainage layer, to protect the latter from intrusion by plant roots or burrowing animals. This layer adds depth to the surface layer, increasing its water storage capacity and protecting underlying layers from freezing and erosion. In many cases, the protection layer and the surface layer are combined to form a single cover layer.

## What types of materials can be used in the protection layer?

**Soil** will generally be the most suitable material for this layer, except in cases where special design requirements exist for the protection layer. The advantages and disadvantages of using soil in the protection layer are the same as those stated above in the discussion of the surface layer topsoil. Factors impacting the thickness and type of soil to use as a protection layer include freeze and thaw properties and the interaction between the soil and drainage layers. Other types of materials that may be used in the protection layer include cobbles with a geotextile filter, gravel and rock, and recycled or reused waste.

**Cobbles with a geotextile filter** can form a good barrier against penetration by plant roots and burrowing animals in arid sites. The primary disadvantage is that cobbles have no water storage capacity and allow water percolation into underlying layers.

**Gravel and rock** are similar to cobbles since they can form a good barrier against penetration by plant roots and burrowing animals. Again, this use is usually only considered for arid sites, because gravel and rocks have no water storage capacity and allow water percolation into underlying layers.

**Recycled or reused waste materials** such as fly ash and bottom ash may be used in the protection layer, when available. Check with the state agency to verify that use of these materials is allowable. The advantages of using these materials in the protection layer are that they store water that has infiltrated past the surface layer, which can then be returned to the surface through evapotranspiration, and that they offer protection against burrowing animals and penetration by roots. If planning to use waste material in the protection layer, consider its impact on surface run-off at the unit's perimeter. Design controls to ensure run-off does not contribute to surface-water contamination. Consult the chapter on protecting surface water for more details on designing run-off controls.

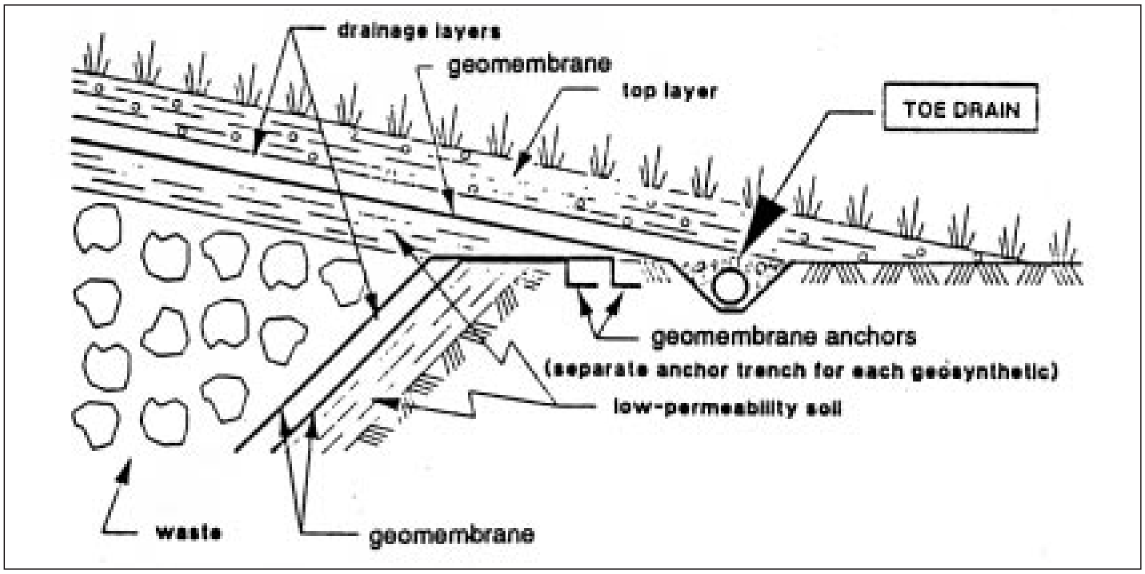
## What function does the drainage layer serve?

A drainage layer may be placed below the surface layer, but above the barrier layer, to direct infiltrating water to drainage systems at the toe of the cover (see Figure 2). For drainage layers, the thickness will depend on the level of performance being designed and the properties of available materials. For example, some geonet composites, with a minimal thickness of less than 1 inch, may have a transmissivity equal to a much thicker layer of aggregate or sand. The recommended thickness of the low permeability soil drainage layer is 12 inches with at least a 3 percent slope at the bottom of the layer. Based on standard practice, the drainage layer should have a hydraulic conductivity in the range of $10^{-2}$ to $10^{-3}$ cm/sec. Water infiltration control through a drainage layer improves slope stability by reducing the duration of surface and protection layer saturation. In this role, the drainage layer works with vegetation to remove infiltrating water from the cover and protect the underlying barrier layer. If this layer drains the overlying soils too well, it could lead to the need for irrigation of the surface layer to avoid desiccation. Another consideration for design of drainage layers is that the water should discharge freely from the layer at the base of the cover. If outlets at the base become plugged or are not of adequate capacity, the toe of the slope may become saturated and potentially unstable. In addition, when designing the drainage layer, consider using flexible corrugated piping in conjunction with either the sand and gravel or the gravel with geotextile filter material to facilitate the movement of water to the unit perimeter.

## What materials can be used in the drainage layer?

**Sand and gravel** are a common set of materials used in the drainage layer. The principal consideration in their use is the conductivity required by the overall design. There may be cases in which the design requires the drainage of a large amount of water from the surface layer, and the hydraulic properties of the sand and gravel layer may be insufficient to meet these requirements. The advantages of using sand and gravel in the drainage layer include the ability to protect the underlying barrier layer from intrusion, puncture, and temperature extremes. The principal disadvantage to these materials is that they are subject to intrusion from the overlying protective layer that may alter their hydraulic conductivity. Similarly, fines in the sand and gravel can migrate downslope, undermining the stability of the cover slope. A graded filter or a geotextile filter can be used to separate and protect the sand

**Figure 2. Drainage Layer Configuration**



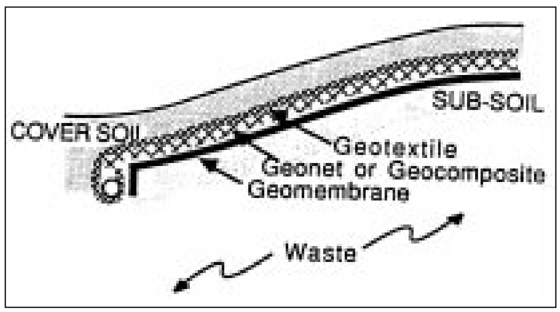

Source: U.S. EPA. 1991. Design and construction of RCRA/CERCLA final covers

and gravel from intrusion by the overlying protection layer.

**Gravel with a geotextile filter** is also a widely-used design, whose applicability may be limited by the local availability of materials. The gravel promotes drainage of water from the overlying layers, while the geotextile filter prevents the clogging of granular drainage layers. Again, be aware of the possibility that a gravel drainage layer may drain overlying soils so well that irrigation of the surface layer may become necessary. The principal advantage to a gravel/geotextile drainage layer is the engineering community's considerable body of knowledge regarding their use as drainage materials. Other advantages include their ability to protect underlying layers from intrusion, puncture, temperature extremes, and their common availability. The geotextile filter provides a cushion layer between the gravel and the overlying protection layer.

**Geonet with geotextile filter** materials can be used to form an effective drainage layer directly above a compacted clay or geomembrane liner (see Figure 3). They may be a suitable alternative in cases where other materials, such as sand and gravel, are not locally available. The principal advantage is that lightweight equipment can be used during installation, reducing the risk of damaging the underlying barrier layer.

**Figure 3.
Geonet with Geotextile Filter Design for Drainage Layer**




Source: U.S. EPA. 1991. Design and construction of RCRA/CERCLA final covers.

The disadvantages associated with these materials are that they provide little protection for the barrier layer against extreme temperature changes, and there can be slippage between the geocomposite interfaces with geomembranes, geotextiles, or low permeability soil barrier materials. Furthermore, problems can arise in the horizontal seaming of the geotextile drainage layer on long slopes.

**Chipped or shredded tires** are an additional option for drainage layer materials. These have been used for bottom drainage layers in the past and may be suitable for cover drainage layers as well. Consult with the state agency to determine whether this option is an acceptable practice.

## What function does the barrier layer serve?

The barrier layer is the most critical component of the cover system because it prevents water infiltration into the waste. It also indirectly promotes the storage and drainage of water from the overlying protection and surface layers, as well as preventing the upward movement of gases. This layer will be the least permeable component of the final cover system. Typically, the hydraulic conductivity of a barrier layer is between $10^{-9}$ to $10^{-7}$ cm/sec.

## What types of materials can be used in the barrier layer?

**Single compacted clay liners (CCLs)** are the most common material used as barrier layers in final cover systems. CCL popularity arises largely because of the local availability of materials and the engineering community's extensive experience with their use. Drying and subsidence are the primary difficulties posed by CCLs. When the clay dries, cracks appear and provide preferential pathways along which water may enter the waste, promoting leachate formation, waste decomposition, and gas formation. Dry waste material and gas formation within the unit contribute to drying from below, while a range of climatological conditions, including drought, can affect CCLs from above. Even with extremely thick surface and protection layers, CCLs may still undergo some desiccation.

Clay liners are also vulnerable to subsidence within the waste unit. This problem can first manifest itself during liner construction. As the clay is compacted with machinery, the waste may not provide a stable, even foundation for the compaction process. This will make it difficult to create the evenly measured lifts comprising the liner. As waste settles over time, depressions can form along the top of the CCL. These depressions put differential stresses on the liner, causing cracks which compromise its integrity. For instance, a depression of only 5 to 11 inches across a 6-foot area may be sufficient to crack the liner materials.

**Single geomembrane liners** are sheets of a plastic polymer combined with other ingredients to form an effective barrier to water infiltration. Such liners are simple and straightforward to install, but they are relatively fragile and can be easily punctured during installation or by movement in surface layer materials. The principal advantage of a geomembrane is that it provides a relatively impermeable barrier with materials that are generally available. It is not damaged by temperature extremes and therefore does not require a thick surface layer. The geomembrane is more flexible than clay and not as vulnerable to cracking as a result of subsidence within the unit. The principal disadvantage is that it provides a point of potential slippage at the interface with the cover soils. Such slippage can tear the geomembrane, even if it is anchored.

**Single geosynthetic clay liners (GCLs)** are composed of bentonite clay supported by geotextiles or geomembranes held together with stitching or adhesives. These liners are relatively easy to install and have some self-healing capacity for minor punctures. They are easily repaired by patching. The main disadvantages include low shear strength, low bearing capacity, vulnerability to puncture due to relative thinness, and potential for slippage at interfaces with under- and overlying soil materials. When dry, their permeability to gas makes GCLs unsuitable as a barrier layer for wastes that produce gas, unless the clay will be maintained in a wet state for the entire post-closure period.

**Geomembrane with compacted clay liners** can be used to mitigate the shortcomings of each material when used alone. In this composite liner, the geomembrane acts to protect the clay from desiccation, while providing increased tolerance to differential settlement within the waste. The clay acts to protect the geomembrane from punctures and tearing. Both act as an effective barrier to water infiltration. The principal disadvantage is slippage between the geomembrane and surface layer materials.

**Geomembrane with geosynthetic clay liners** can also be used as a barrier layer. As with geomembrane and CCL combinations, each component serves to mitigate the weakness of the other. The geosynthetic material is less vulnerable than its clay counterpart to cracking and has a moderate capacity to self-heal. The geomembrane combined with the GCL is a more flexible cover and is less vulnerable to differential stresses from waste settlement. Neither component is readily affected by extreme temperature changes, and both work together to form an effective barrier layer. For more information on the properties of geosynthetic clay liners, including their hydration after installation, refer to the chapter on designing and installing liners. The potential disadvantage is slippage between the upper and lower surfaces of the geomembrane and some types of GCL and other surface layer materials. The geomembrane is still vulnerable to puncture, so placement of cover soils is important to minimize such damage.

### What function does the gas collection layer serve?

The role of the gas collection layer is to control the migration of gases to collection vents. This collection layer is a permeable layer that is placed above the foundation layer. It is often used in cases where the foundation layer itself is not the gas collection layer.

### What types of materials can be used in the gas collection layer?

Sand and gravel are the most common materials used for gas collection layers. With these materials, a filter may be needed to prevent infiltration of materials from the barrier layer. Geotextile drains and filters also can make suitable gas collection layers. In many cases, these may be the most cost-effective alternatives. The same disadvantages exist with these materials in the gas collection layer as in other layers, such as slippage and continuity of flow.

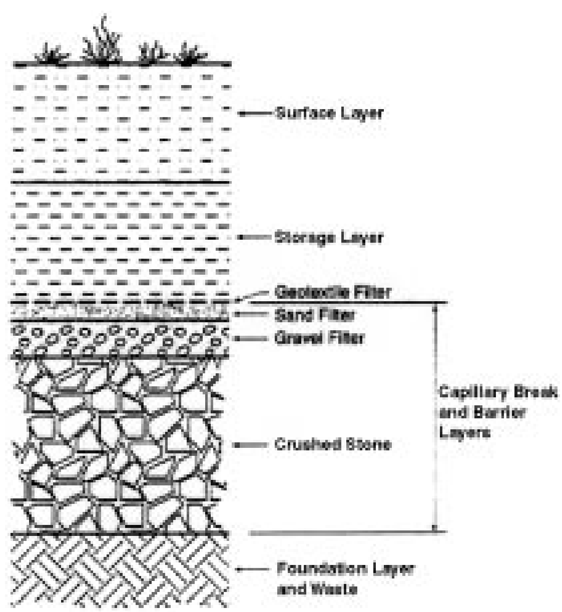
## D. Capillary-Break Final Covers

The capillary-break (CB) approach is an alternative design for a final cover system (see Figure 4). This system relies on the fact that for adjacent layers of fine- and coarse-textured soil to be in water-potential equilibrium, the coarse-grained soil (such as crushed stone) will tend to have a much lower water content than the fine-grained soil (such as sand). Furthermore, the conductivity of water through a soil decreases exponentially with its water content, or stated another way, as a soil becomes more dry, its tendency to stay dry increases. Therefore, as long as the strata in a capillary break remain unsaturated (remain above the water table), the overlying fine-textured soil will retain nearly all the water and the coarse soil will behave as a barrier to water percolation due to its dryness. Since this phenomenon breaks down if the coarse layer becomes saturated, this alternative cover system is most appropriate for semiarid and desert environments.

## What types of materials are used in capillary-break covers?

The CB cover system typically consists of five layers: surface, storage, capillary-break, barrier, and foundation. The surface, barrier, and foundation layers play the same role in the cover system as described above. The storage layer consists of fine material, such as silty sand. The capillary-break, or coarse, layer consists of granular materials, such as gravel and/or coarse sand. A fabric filter is often placed between the coarse and fine layers.

**Figure 4. Example of a Capillary-Break Final Cover System**




Adapted from
**<www.hanford.gov/eis/hraeis/eisdoc/graphics/fige-1.gif>**

# E. The Hydrologic Evaluation of Landfill Performance (HELP) Model

The relative performance of various cover designs can be evaluated with the Hydrologic Evaluation of Landfill Performance (HELP) model, developed by the U.S. Army Corps of Engineers Waterway Experiment Station for EPA (U.S. EPA 1988). The HELP model was designed specifically to support permit writers and engineers in evaluating alternative landfill designs but it can also be used to evaluate various final cover designs.

The HELP model integrates run-off, percolation, and subsurface-water flow actions into one model. The HELP model can be used to estimate the flow of water across and through a final cover. To achieve this, the HELP model uses precipitation and other climatological information to partition rainfall and snow melt into surface run-off, evaporation, and downward infiltration through the barrier layer to the waste. The HELP model essentially divides a waste management unit into layers, each defined in terms of soil type, which is related to the hydraulic conductivity of each. Users fill in data collection sheets that request specific information on the layers and climate, and this information is input to the model. In performing its calculations, the model will take into account the reported engineering properties of each layer, such as slope, hydraulic conductivity, and rates of evapotranspiration, to estimate the amount of precipitation that may enter the waste unit through the final cover. To use the HELP model properly, refer to the HELP Model User's Guide and documentation (U.S. EPA. 1994b, U.S. EPA. 1994c). The HELP model, User's Guide, and supporting documentation may be obtained by calling the National Technical Information Service (NTIS) at 800 553-6847.

Table 2
Types of Recommended Final Cover Systems

| Type of Bottom Liner | Recommended Cover System Layers (From top layer down) | Thickness (In inches) | Hydraulic Conductivity (In cm/sec) |
|---|---|---|---|
| Double Liner | Surface Layer | 12 | not applicable |
| | Drainage Layer | 12[a] | $1x10^{-2}$ to $1x10^{-3}$ |
| | Geomembrane | 30mil (PVC) 60mil (HDPE) | - |
| | Clay Layer | 18 | less than $1x10^{-5}$ |
| Composite Liner | Surface Layer | 12 | not applicable |
| | Drainage Layer | 12[a] | $1x10^{-2}$ to $1x10^{-3}$ |
| | Geomembrane | 30mil (PVC) 60mil (HDPE) | - |
| | Clay Layer | 18 | less than $1x10^{-5}$ |
| Single Clay Liner | Surface Layer | 12 | not applicable |
| | Drainage Layer | 12[a] | $1x10^{-2}$ to $1x10^{-3}$ |
| | Clay Layer | 18 | less than $1x10^{-7}$ |
| Single Clay Liner in an Arid Area | Cobble Layer | 2-4 | not applicble |
| | Drainage Layer | 12[a] | $1x10^{-2}$ to $1x10^{-3}$ |
| | Clay Layer | 18 | less than $1x10^{-7}$ |
| Single Synthetic Liner | Surface Layer | 12 | not applicable |
| | Drainage Layer | 12[a] | $1x10^{-2}$ to $1x10^{-3}$ |
| | Geomembrane | 30mil (PVC) 60mil (HDPE) | - |
| | Clay Layer | 18 | less than $1x10^{-5}$ |
| Natural Soil Liner | Earthen Material | 24[b] | No more permeable than base soil |

[a]This recommended thickness is for low permeability soil material with at least a 3 percent slope at the bottom of the layer. Some geonet composites, with a minimal thickness of less than 1 inch, may have a transmissivity equal to a much thicker layer of aggregate or sand.

[b]Thickness may need to be increased to address freeze/thaw conditions.

## F. Recommended Cover Systems

Figures 5 through 9 present recommended minimum final cover systems. The recommended final cover systems correspond to a waste management unit's bottom liner system. A unit with a single geomembrane bottom liner system, for example, should include, at a minimum, a single geomembrane in its final cover system unless an evaluation of site-specific conditions shows an equivalent reduction in infiltration. Table 2 above summarizes the recommended final cover systems based on the unit's bottom liner system. While the recommended minimum final cover systems

**Figure 5. Final Cover System for a Unit With a Double or Composite Liner**

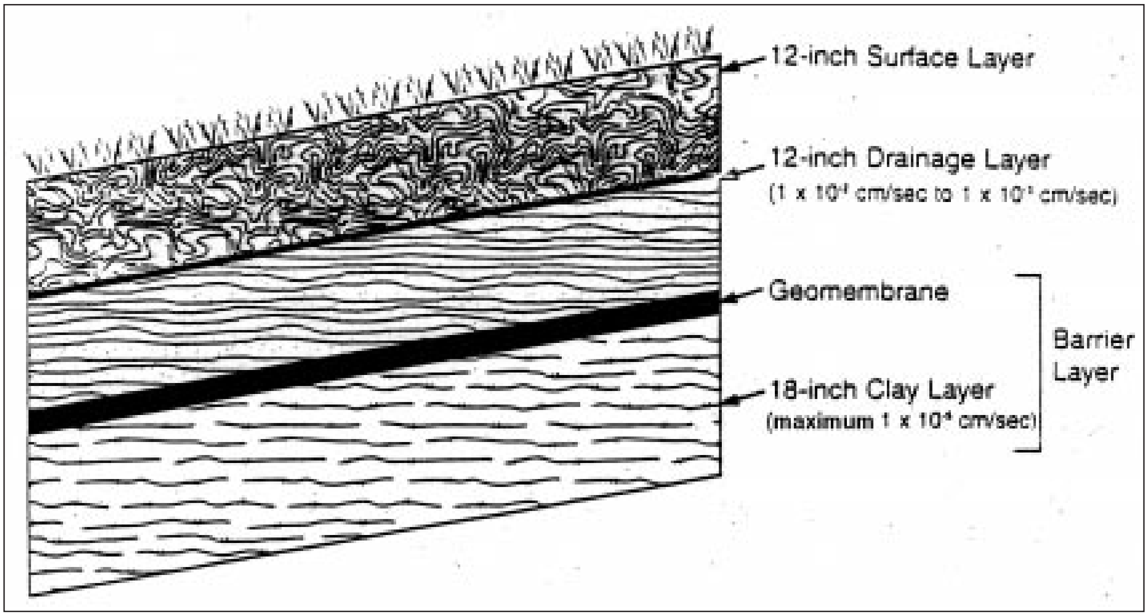



**Figure 6. Final Cover System for a Unit With a Single Layer Clay Liner**

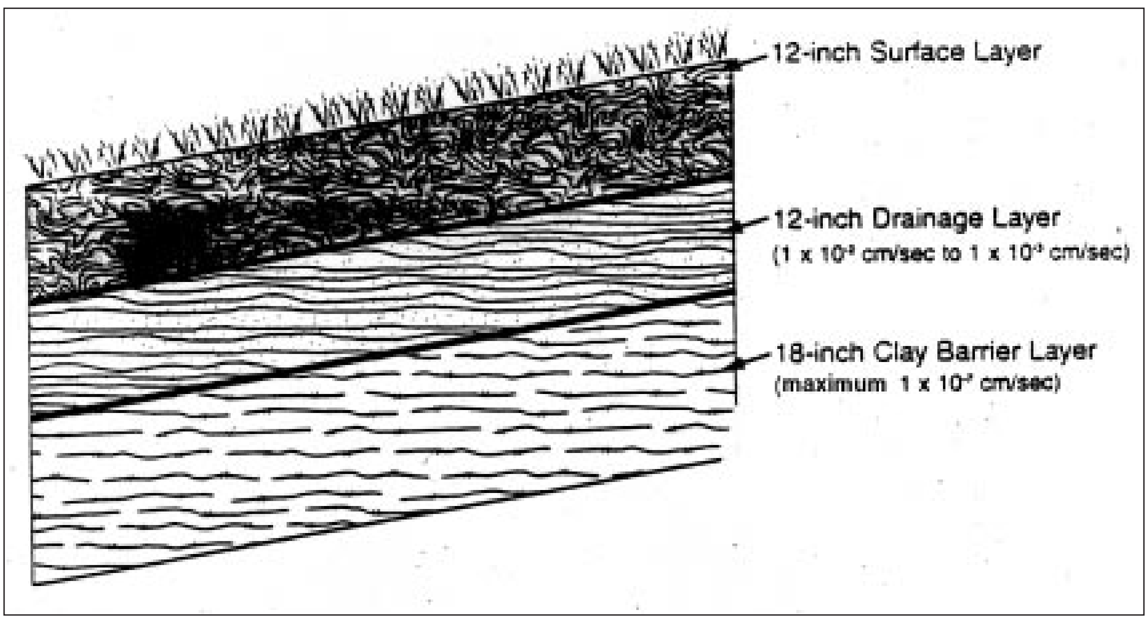


**Figure 7. Final Cover System for a Unit With a Single Clay Liner in an Arid Area**

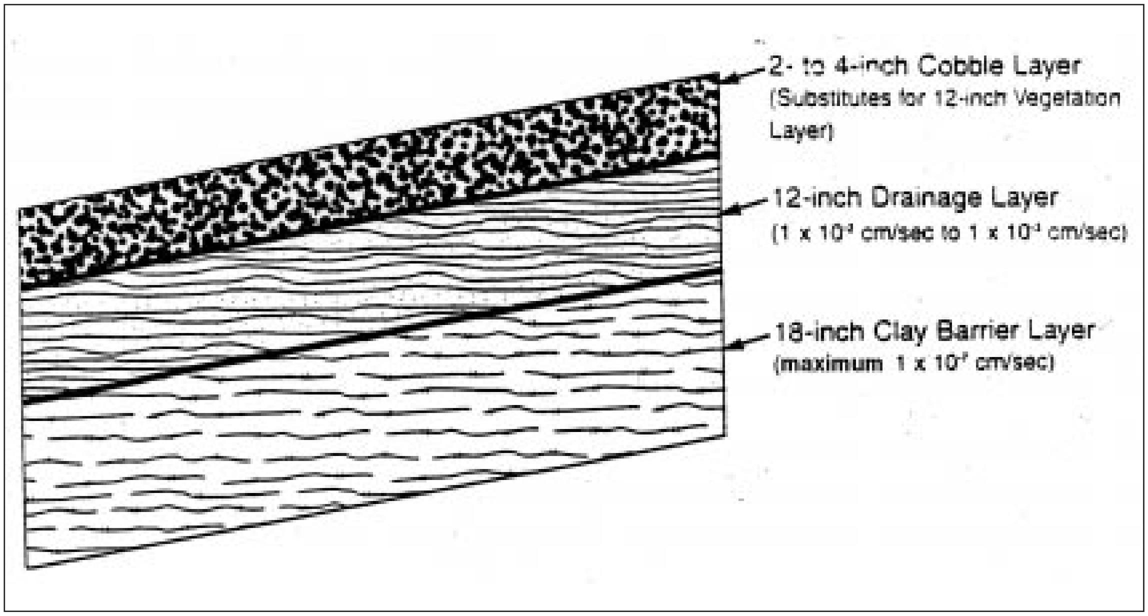



**Figure 8. Final Cover System for a Unit With a Single Synthetic Liner**

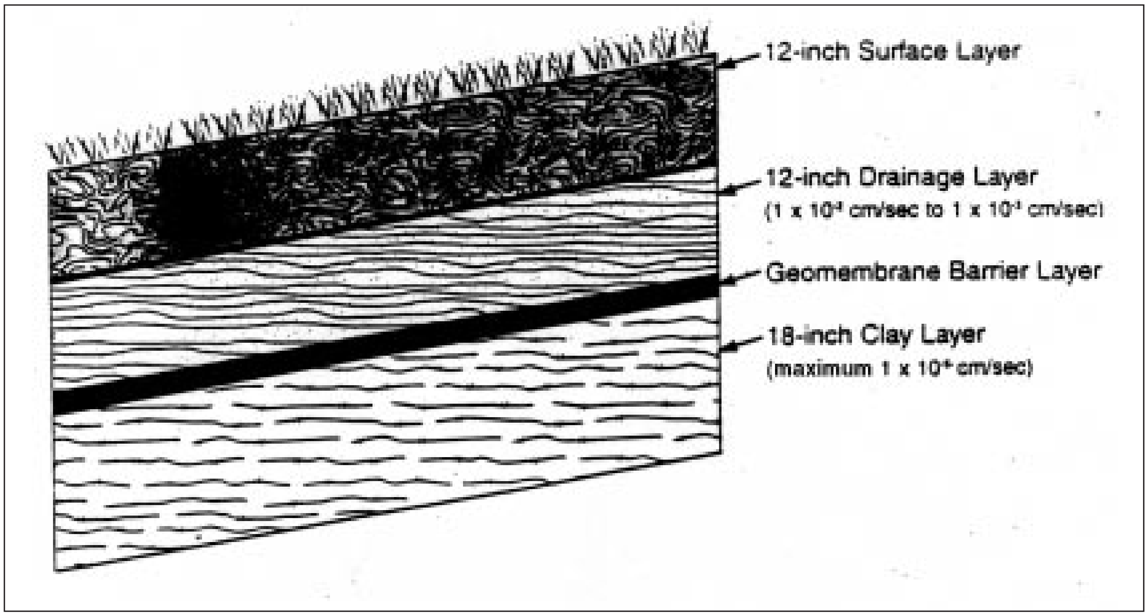
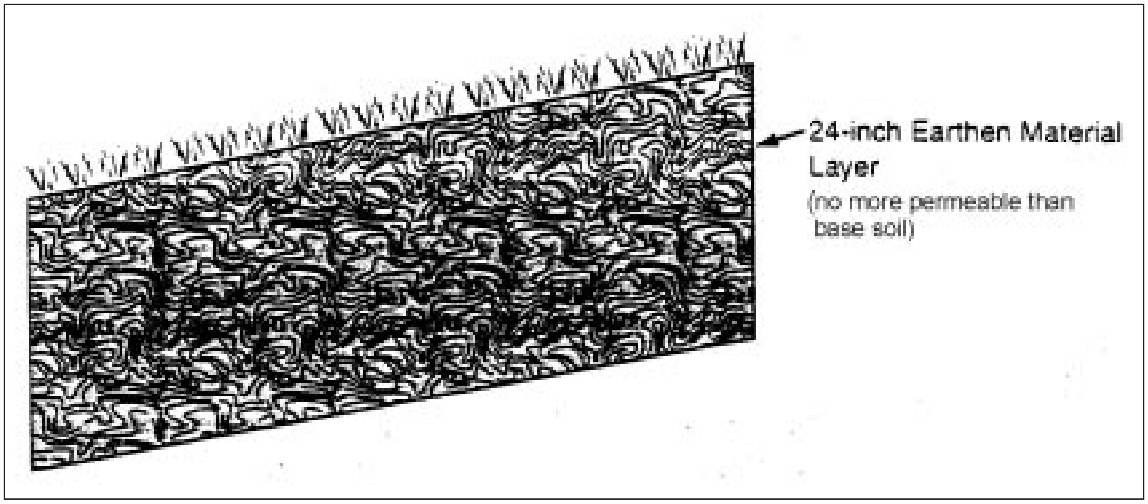


**Figure 9. Final Cover System for a Unit With a Natural Soil Liner**




include closure layer component thicknesses and hydraulic conductivity, the cover systems can be modified to address site-specific conditions. In addition, consider whether to include a protection layer or a gas collection layer.

# IV. Closure by Waste Removal

Closure by waste removal is a term that describes the removal and decontamination of all waste, waste residues, contaminated ground water, soils, and containment devices. This approach is common for waste piles and some surface impoundments.

Removal and decontamination are complete when the constituent concentrations throughout the unit and any areas affected by releases from the unit do not exceed numeric cleanup levels. Check with the state agency to see if it has established any numeric cleanup levels or methods for establishing site-specific levels. In the absence of state cleanup levels, metals and organics should be removed to either statistically equivalent background levels or to maximum contaminant levels (MCLs) or health-based numbers (HBNs).[1] Metals and organics may have different cleanup levels, but they both need to be based on either local background levels or on health-based guidelines. Future land use considerations may also be important in determining the appropriate level of cleanup. One tool that can be used to help evaluate whether waste removal is appropriate at the site is the risk-based corrective action (RBCA) process described in the chapter on taking corrective action. The RBCA process provides guidance on integrating ecological and human health risk-based decision-making into the traditional corrective action process.

## A. Establishing Baseline Conditions

As a good management practice, establish the baseline conditions for a waste management unit. Baseline conditions are the background constituent concentrations at a site prior to waste placement operations. Identifying the types of contaminants that may be present, provides an indication of the potential contamination resulting from the operation of a unit and the level of effort and resources that may be required to reach closure.

[1]Access the Integrated Risk Information System (IRIS), a database of human health effects that may result from exposure to environmental contaminants, to learn about the regulatory and technical basis for MCLs at <www.epa.gov/ngispgm3/iris/Regulatory.html>. Call the EPA Risk Information Hotline at 513 569-7254 for more information.

Naturally-occurring elevated background levels that are higher than targeted closure levels may be encountered. In such cases, consult with the state agency to determine whether these elevated background levels are a more appropriate targeted cleanup level. The identification of potential contaminants will also provide a guideline for selecting sampling parameters. In the event that constituents other than those initially identified are discovered through subsequent soil and water sampling, this may indicate that contaminants are migrating from another source.

In some cases, waste contaminants may have been present at the site before a waste management unit was constructed or migrated to the site from another unrelated source. In these situations, closure may still proceed, provided that any contamination originating from the closing unit is removed to appropriate cleanup levels. Determine whether additional remediation is required under other federal or state laws, such as the Resource Conservation and Recovery Act (RCRA) or the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) or state cleanup laws.

### How should I establish baseline conditions?

Initial soil and ground-water sampling around, within, and below a unit will serve to identify baseline conditions. Sampling can detect contaminant levels that exceed background levels or federal, state, or local health-based benchmarks. Contact local environmental protection officials for guidance on the number and type of samples that should be taken. If the initial round of sampling does not reveal any contaminant levels that exceed benchmarks, proceed with the removal of waste and the restoration of the unit. If the sampling does reveal contamination that exceeds the benchmarks, consider ways to remediate the site in compliance with federal, state, or local requirements.

## B. Removal Procedures

Proper removal procedures are vital to the long-term, post-closure care of a unit and surrounding land. Properly removing waste, can minimize the need for further maintenance, thereby saving time and money and facilitating reuse of the land. Perform closure by waste removal in a manner that prevents the escape of waste constituents to the soil, surface water, ground water, and atmosphere. After removing the waste, remove all equipment, bases, liners, soils, and any other materials containing waste or waste residues. Finally, the land should be returned to the appearance and condition of surrounding land areas to the extent possible consistent with the closure and post-closure plans.

### Should I have a plan for waste removal procedures?

The waste removal process should be fully described in a closure plan. The removal process description should address estimates of the volumes and types of waste and contaminated equipment or structures to be removed during closure. It should also include the types of equipment to be used, the removal pattern, and the management of loading areas. The closure plan should also detail actions to be taken to minimize and/or prevent emissions of waste during closure activities. For example, if activities during closure include loading and transporting waste in trucks, the closure plan should describe the steps that will be taken to minimize air emissions from windblown dust. Proper quality assurance and quality control during the waste removal process will help ensure that the removal proceeds in accordance with the waste removal plan. A key component of the waste removal procedure is the consideration of proper disposal of any wastes or contaminated materials.

## C. Disposal of Removed Wastes

When a unit is closed by removing waste, waste residues, contaminated ground water, soils, and containment devices, ensure that disposal of these materials is in compliance with state law. If the composition of the waste can not be determined using process knowledge, test it using procedures such as those described in the chapter on characterizing waste. Then consult with the state agency to determine what requirements apply to waste of that kind.

## D. Final Sampling and Analysis

The purpose of final sampling and analysis is to ensure that target cleanup levels have been achieved. While initial sampling is intended to establish baseline levels of contaminants, final sampling is used more as a safeguard to make sure levels have not changed. It is important to conduct a final sampling, in addition to the initial sampling, because removal actions can increase the contaminant levels at the site, and sometimes contamination is overlooked in the initial baseline sampling event.

### Is it necessary to develop a sampling and analysis plan?

Because of the importance of accurate sampling, develop a sampling and analysis plan to ensure correct sampling procedures. This plan should include information on selection of sampling locations, sampling protocols, methods, quality assurance and quality control procedures, and procedures for analysis of samples and reporting results. The plan should also address the selection of analytical constituents, based on current and historic operations at the facility and closing unit, and the initial review of the wastes present in the unit. Consult with qualified professionals and the state agency to develop the plan and conduct and analyze sampling activities.

Guidance for sample collection, preservation, preparation, and analysis can be found in the following standard testing methods:

- Test Methods for Evaluating Solid Waste, Physical Chemical Methods, Third Edition, U.S. EPA, SW-846
- Methods for Chemical Analysis of Water and Wastes, U.S. EPA, EPA600-4-79-020;
- Standard Methods for the Examination of Water and Wastewater, American Society for Testing Materials (ASTM), American Public Health Association, American Water Works Association, and Water Pollution Control Federation; and
- The ASTM Standard Test Methods for Analysis of Water and Wastes.

### How should the sampling data be used?

The results of this sampling event should be compared to the results of the baseline event, and any discrepancies should be noted. The results can be compared to performance measures established at the beginning of the closure process with state or local regulators. Closure plans incorporating waste removal should include a sampling and analysis plan for the initial and final sampling and analysis efforts. The plan should specify procedures to ensure that sample collection, handling, and analysis will result in data of sufficient quality to plan and evaluate closure activities. The sampling and analysis plan should be designed to define the nature and extent of contamination at/or released from the closing unit. The level of detail in the sampling and analysis plan should be commensurate with the complexity of conditions at the closing unit.

# V. Post-Closure Care Considerations When Final Cover Is Used

For units that will close with a final cover, consider the following factors:

- Routine maintenance of the unit's systems, including the final cover, leachate collection and removal systems, surface-water controls, and gas and ground-water monitoring systems where appropriate;
- The names and telephone numbers of facility personnel for emergencies;
- Mechanisms to ensure the integrity of the final cover system, such as posted signs or notifications on deeds;
- The anticipated uses of the property during the post-closure period;
- The length of the post-closure care period;
- Costs to implement post-closure care; and
- Conditions that will cause post-closure care to be extended or shortened.

## A. Maintenance

After the final cover is installed, some maintenance and repair will be necessary to keep the cover in good working condition. Maintenance may include mowing the vegetative cover periodically and reseeding, if necessary. Repair the cover when erosion or subsidence occurs. Maintaining healthy vegetation will ensure the stability of slopes, reduce surface erosion, and reduce leachate production by increasing evapotranspiration. A regular schedule for site inspections of maintenance activities during the post-closure period, as well as prompt repair of any problems found at inspection, may help ensure the proper performance of the cover system. Maintenance of the proper thickness of surface and drainage layers will ensure long-term minimization of liquids and protection of geomembranes, if present.

### What maintenance and repair activities should I conduct after the final cover has been installed?

In the case of damage to the final cover, determine the cause of damage, so that proper repair measures may be taken to prevent recurrence. For example, if the damage is due to erosion, potential causes may include the length and steepness of slopes, insufficient vegetation growth due to poor planting, or uneven settlement of the waste. Sedimentation basins and drainage swales should be inspected after major storms and repaired or cleaned, as necessary.

Components of the leachate collection and removal system, such as leachate collection pipes, manholes, tanks, and pumps should also receive regular inspection and maintenance. If possible, flush and pressure-clean the collection systems on a regular basis to reduce sediment accumulation and to prevent clogging caused by biological growth. The manholes, tanks, and pumps should be visually inspected at least annually, and valves and manual controls should be exercised even more frequently, because leachate can corrode metallic parts. Repairs will help prevent future problems, such as leachate overflow from a tank due to pump failure.

Inspect and repair gas and ground-water monitoring wells during the post-closure period. Proper operation of monitoring wells is essential to determine whether releases from a closed waste management unit are occurring. For example, ground-water monitoring wells should be inspected to ensure that they have not been damaged by vehicular traffic or vandalism. Physical scraping or swabbing may be necessary to remove biological clogging or encrustation from calcium carbonate deposits from well screens.

## B. Monitoring During Post-Closure Care

Post-closure care monitoring should include the leachate collection system, surface-water controls, the ground-water monitoring system where appropriate, and gas controls where appropriate. Post-closure monitoring will serve as your main source of information about the integrity of the final cover and liners.

### What should I consider when monitoring post-closure leachate, ground water, and gas?

The quantity of leachate generated should be monitored, as this is a good indicator of the performance of the closure system. If the closure system is effective, the amount of leachate generated should decrease over time. In addition, the concentration of contaminants in leachate should, in time, reach an equilibrium. An abrupt decline in the contaminant concentration could mean that the cover has failed, and surface water has entered the waste and diluted the leachate.

To ensure leachate has not contaminated ground-water supplies, sample ground water regularly. Regular ground-water monitoring detects changes, or the lack thereof, in the quality of ground water. For a more detailed discussion, consult the chapter on monitoring performance.

As no cover system is impermeable to gas migration, if gas production is a concern at the unit install gas monitoring wells around the perimeter of the unit to detect laterally moving gas. If geomembranes are used in a cover, more gas may escape laterally than vertically. Gas collection systems can also become clogged and stop performing properly. Therefore, periodically check gas vents and flush and pressure-clean those vents not working properly.

## C. Recommended Length of the Post-Closure Care Period

The overall goal of post-closure care is to provide care until wastes no longer present a threat to the environment. Threats to the environment during the post-closure care period can be evaluated using leachate and ground-water monitoring data to determine whether there is a potential for migration of waste constituents at levels that might threaten human health and the environment. Ground-water monitoring data can be compared to drinking water standards or health-based criteria to determine whether a threat exists.

Leachate volumes and constituent concentrations may also be used to show that the unit does not pose a threat to human health and the environment. The threats posed by constituent concentrations in leachate should be evaluated based on potential release of leachate to ground water and surface waters. Consequently, consider doing post-closure care maintenance for some period of time. Individual post-closure care periods may be long or short depending on the type of waste being managed, the waste management unit, and a variety of site-specific characteristics. Contact the state agency to determine what post-closure period the state agency recommends. In the absence of any state guidance on the appropriate length of the post-closure period, consider a minimum of 30 years.

## D. Closure and Post-Closure Cost Considerations

The facility manager of a closed industrial unit, is responsible for that unit. To ensure long-term protection of the environment, account for the costs of closure and post-closure care when making initial plans. There are guidance documents available to help plan for the costs associated with closing a unit. For example, estimating guides by the R.S. Means Co. provide up-to-date costs for most construction-related work, such as moving soil, cost of material and labor for installing piping. Appendix I also presents an example of a closure/post-closure cost estimate form. Appendix II contains some sample cost estimating worksheets to assist in determining the cost of closure.[2] Also consider obtaining financial assurance mechanisms so that the necessary funds will be available to complete closure and post-closure care activities if necessary. Financial assurance fosters long-range financial planning and encourages internalization of the future costs associated with waste management units. It also promotes proper design and operating practices, because the costs for closure and post-closure care are often less for units operated in an environmentally protective manner. Check with the state agency to determine whether financial assurance is required and what types of financial assurance mechanisms may be acceptable.

The amount of necessary financial assurance is based on site-specific estimates of the costs of closure and post-closure care. The estimates should reflect the costs that a third party would incur in conducting closure and post-closure activities. This recommendation ensures adequate funds will be available to hire a third party to carry out necessary activities. Consider updating the cost estimates annually to account for inflation and whenever changes are made to the closure and post-closure plans. For financial assurance purposes, if a state does not have a regulation or guidance regarding the length of the post-closure care period, 30 years should be used as a planning tool for developing closure and post-closure cost estimates.

Financial assurance mechanisms do not force anyone to immediately provide full funding for closure and post-closure care. Rather, they ensure future availability of such funds. For example, trust funds may be built up gradually during the operating life of a waste management unit. By having an extended "pay-in" period for trust funds, the burden of funding closure and post-closure care will be spread out over the economic life of the unit. Alternatively, use a corporate financial test or third-party alternatives, such as surety bonds, letters of credit, insurance, or guarantees.

[2]These worksheets were generated from CostPro©: Closure and Post-Closure Cost Estimating Software. CostPro© is available for a fee from Tetra Tech EM Inc.. Contact Steve Jeffords at 404 225-5514, or 285 Peach Tree Center Avenue, Suite 900, Atlanta, GA, 30303.

## What costs can I expect to be associated with the closure of a unit?

The cost of constructing a final cover or achieving closure by waste removal will depend on site-specific activities. Consider developing written cost estimates before closure procedures begin. For closure by means of a final cover, the cost of constructing the final cover will depend on the complexity of the cover profile, final slope contours of the cover, whether the entire unit will be closed (or partial closures), and other site-specific factors. For example, the components of the final cover system, such as a gas vent layer or biotic layer, will affect costs. In addition, closure cost estimates would also include final cover vegetation, run-on and run-off control systems, leachate collection and removal systems, ground-water monitoring wells, gas monitoring systems and controls, and access controls, such as fences or signs. Closure costs may also include costs for construction quality assurance costs, engineering fees, accounting and banking fees, insurance, permit fees, legal fees, and, where appropriate, contingencies for cost overruns, reworks, emergencies, and unforeseen expenses.

For closure by means of waste removal, closure costs would include the costs of removal procedures, decontamination procedures, and sampling and analysis. Closure costs should also consider the costs for equipment to remove all waste, transport it to another waste management unit, and properly dispose of it. In addition, fugitive dust emission controls, such as dust suppression practices, may need to be included as a closure cost.

## What costs can I expect to be associated with post-closure care?

After a waste management unit is closed, conduct monitoring and maintenance to ensure that the closed unit remains secure and stable. Consider the costs to conduct post-closure care and monitoring for at least 30 years (in the absence of a state regulation or guidance). If a unit is successfully closed by means of waste removal, no post-closure care costs would be expected. Post-closure care costs should include both annual costs, such as monitoring, and periodic costs, such as cap or monitoring well replacement.

For units closed by means of a final cover, consider the costs for a maintenance program for the final cover and associated vegetation. This program may include repair of damaged or stressed vegetation, and maintenance of side slopes. Costs to maintain the run-on and run-off control systems, leachate collection and removal systems, and ground-water and gas monitoring wells should also be expected. In addition, sampling and analysis costs may need to be factored into the post-closure cost estimates.

Post-closure costs should be updated annually as a record of actual unit costs is developed. Some costs, such as erosion control and ground-water sampling, may be reduced over time as the vegetation on the cover matures and a meaningful amount of monitoring data is accumulated. Due to site-specific conditions, a shorter or longer post-closure period may be determined to be appropriate.

## How can I obtain long-term financial assurance for my unit?

Some of the different forms of financial assurance mechanisms include prepayment, surety, insurance, guarantee, corporate guarantees, and financial tests. Prepayment is a method whereby cash, liquid assets, certificates of deposit, or government securities are deposited into a fund controlled by a trustee, escrow agent, or state agency. The prepayment amount should be such that the principal plus accumulated earnings over the projected life of the waste management unit would be sufficient to pay closure and post-closure care costs. Surety, insurance, and guarantee are methods to arrange for a third party to guarantee payment for closure and post-closure activities if necessary. A financial test is an accounting ratio, net worth, bond rating, or combination of these standards that measures the financial strength of a firm. By passing a financial test, it is determined that one has the financial strength to pay for closure and post-closure costs.

A more detailed list of examples of financial assurance mechanisms may be found in Appendix III. These mechanisms may be used individually or in combination. This guidance, however, does not recommend specific acceptable financial assurance mechanisms.

## Action Items for Performing Closure and Post-Closure

Consider the following while developing closure and post-closure care activities for industrial waste management units.

❑ Develop a closure and post-closure plan, specifying the activities, unit type, waste type, and schedule of the closure.

❑ If using a final cover to accomplish closure:

— Include the specifications for the final cover in the closure plan;

— Determine whether the waste will need stabilization or solidification prior to constructing the final cover;

— Address site-specific factors that may affect cover performance;

— Select the appropriate materials to use for each layer of the final cover;

— Evaluate the effectiveness of the final cover design using an appropriate methodology or modeling program;

— Establish a maintenance plan for the cover system;

— Establish a program for monitoring leachate collection, ground-water quality, and gas generation during the post-closure period; and

— Ensure proper quality assurance and quality control during final cover installation and post-closure monitoring.

❑ If accomplishing closure by waste removal:

— Include estimates of the waste volume and contaminated equipment to be removed during closure;

— Establish baseline conditions and check to see if the state requires numeric cleanup levels;

— Develop removal procedures;

— Develop a sampling and analysis plan; and

— Ensure proper quality assurance and quality control during sampling and

## Action Items for Performing Closure and Post-Closure (cont.)

- ❑ Determine what post-closure activities will be appropriate at the site.
- ❑ Estimate the costs of closure and post-closure care activities and consider financial assurance mechanisms to help plan for these future costs.

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